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GENERIC ASTRONOMY MISSION PLANNING AND SCHEDULING:
THE AXAF SOLUTION

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During SPACEOPS92 the idea of generic mission planning concepts for space astronomy missions, that could be applied to future missions in order to simplify software development, was introduced. It was proposed that mission planning systems could be decomposed into functional elements that could be standardized and then organized into optimal functional flows for each individual mission. In addition, it was further suggested that these flows themselves could be reduced to a small set of possibilities by describing them in terms of generic mission type, such as manned, unmanned, high orbit, low orbit, etc. The Advanced X-ray Astrophysics Facility (AXAF), planned for launch in the latter part of '98, represents the first application of this idea on an unmanned mission. This paper examines the AXAF Mission Planning and Scheduling concept in light of the generic system theory. Each functional element is evaluated according to AXAF characteristics and requirements and then compared to its generic counterpart. Functional flow considerations are then derived from the overall AXAF mission planning concept to determine the viability and sensitivity of the generic flow to actual requirements. The results of this analysis are then used to update the generic system concept and to define the level of commonality and core system components that are practical to achieve across multiple missions.

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Generic Mission Planning and Scheduling: The AXAF Solution

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ABSTRACT

During SpaceOps 92 the idea of generic mission planning concepts for space astronomy missions, that could be applied to future missions in order to simplify software development, was introduced. It was proposed that mission planning systems could be decomposed into functional elements that could be standardized and then organized into optimal functional flows for each individual mission. In addition, it was further suggested that these flows themselves could be reduced to a small set of possibilities by describing them in terms of generic mission type, such as manned, unmanned, high orbit, low orbit, etc. The Advanced X-ray Astrophysics Facility (AXAF), planned for launch in the latter part of '98, represents the first application of this idea on an unmanned mission. This paper examines the AXAF Mission Planning and Scheduling concept in light of the generic system theory. Each functional element is evaluated according to AXAF characteristics and requirements and then compared to its generic counterpart. Functional flow considerations are then derived from the overall AXAF mission planning concept to determine the viability and sensitivity of the generic flow to actual requirements. The results of this analysis are then used to update the generic system concept and to define the level of commonality and core system components that are practical to achieve across multiple missions.

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INTRODUCTION

The recent emphasis on smaller, cheaper and faster satellite development has led to a corresponding reduction in ground support system funding. This trend manifests itself not only in control center hardware architecture, but in software system design as well. Several control centers already exist that support multiple missions and it is expected that this will in the future be the norm. A natural extension of this philosophy is a concomitant thrust by ground system designers to devise generic on-line support software and, to a lesser extent, the off-line software used for spacecraft operations and control. The latter, especially, has been more difficult to bring about because of unique science instrument and satellite characteristics and (unlike common control center development) different designers are involved in each project. In the case of AXAF, great emphasis has been placed on generic on-line software and extensive reuse of existing off-line software elements. Simple reuse of appropriate routines, however, is not enough to produce a software system that will be useful for more than one mission; it also requires careful consideration of flexible design features, functional modularity and functional flow. The benefits of a generic system are reduced costs, easier maintenance and updates, reduced user training, and analytical tool spin-offs.

THEORETICAL COMPONENTS

During SpaceOps 92 the idea of a generic mission planning and scheduling system for space astronomy missions was introduced. The theoretical basis for this idea was determined by examination of past and existing systems spanning over 20 years. By comparing similar functional elements in each of these systems, the authors were able to define a set of functions common to every system, although the specific implementation and packaging of these functions varied widely with the passage of time and the

peculiarities of each project. The eight resulting theoretical components of the generic system are listed in Table 1 along with a brief definition of each.

Table 1. Generic Mission Planning Functions

MISSION PLANNING FUNCTIONS

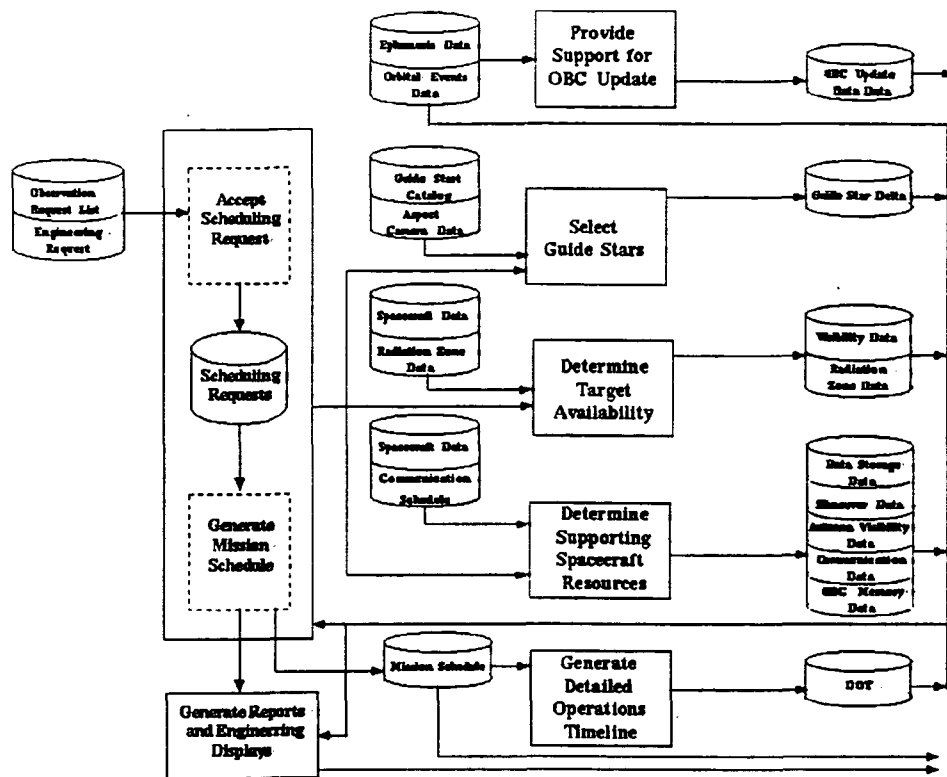
- **Observation & Engineering Request Processing** – Receive, check and edit observation and engineering requests.
- **Orbital Mechanics** – Generate all ephemeris, environmental and geometric data.
- **Guide Star Selection** – Select guide/aspect stars for each observation.
- **Scheduling** – Schedule science and spacecraft activities.
- **Editing** – Modify and revalidate existing schedule.
- **Communications Planning** – Determine communications opportunities.
- **Spacecraft Management** – Generate detailed, chronological list of spacecraft activities to implement schedule.
- **Flight Operations Team Support** – Display and tabulate mission planning data required for flight operations support.

AXAF CONCEPT COMPONENTS

Since SpaceOps 92, two new missions have begun development of their respective mission planning and scheduling systems along the lines of the generic model. Astro-2, a manned Spacelab flight, will reuse much of the Astro-1 software with improvements in the schedule editing, guide star selection and flight operations support areas. The other mission, AXAF, belongs to the unmanned world and is one of the four satellites in the Great Observatories program. It too will reuse much software from previous missions and its off-line software design will emphasize modularity and independence of functional elements.

Although the AXAF Mission Planning and Scheduling system design is in the early prototype stage, a recognizable structural outline of process flow, and the features included in each functional module are emerging. The elements composing this concept and their interaction are depicted in Figure 1. Notice that some of the functional titles in the flow diagram are different than those listed in the generic concept, and that the "packaging" is not always the same. These variances, however, are not detrimental to the generic theory. Specific titles for each function will vary from project to project. What really matters is that each function remain essentially the same regardless of what it's called. As was mentioned in the original paper, it is likewise acceptable to package functions together as needed by specific missions, so long as each function maintains its modularity and standalone capability. The reverse process of splitting subfunctions into separate packages, as is the case in the AXAF solution, is also permissible with the same stipulation.

Figure 1. AXAF Mission Planning and Scheduling Functional Flow



In the AXAF generic solution, the process described above was used liberally. The scheduling, editing and communications planning functions, for example, have been packaged together for convenience due to their close relationships. This allows the user to interact with these functions as needed without having to create intermediate products and migrating between applications windows. The spacecraft management function for AXAF is called the Detailed Operations Timeline (DOT), but otherwise exactly matches the theoretical generic element. The name itself derives from the fact that the DOT contains a complete chronological list of all activities at the mnemonic level and is the final mission planning product that feeds directly into the Command Management System (CMS).

One of the most difficult to define elements of the generic system is what was called (for lack of a more definitive name) "Flight Operations Team Support." In terms of functionality, this element differs from the other elements in that it doesn't have its own unique computational niche; i.e., it is not part of the essential data flow required to operate the spacecraft. It consists instead of information produced in the other elements, but organized and presented in formats suitable for Flight Operations Team support. The AXAF concept has clarified this function considerably by creating a support module called the Interface and Support Software (ISS), formulated by combining selected subfunctions of the Orbital Mechanics element with spacecraft environmental and orientation displays. In conjunction with appropriate scheduler displays, Flight Operations team personnel will be provided with all the mission planning information needed to conduct flight operations.

The advantages of this approach are that duplication of planning tasks and products can be minimized, and that ISS data and displays, which are also needed by other off-line software systems (attitude determination and spacecraft analysis), can be more easily shared. As a generic element, this solution works well because the selected orbital mechanics subfunctions and environmental displays, such as ephemerides and ground tracks are independent of schedule and spacecraft complexities.

A listing of the subfunctions included in each element of the AXAF concept is presented in Table 2.

Table 2. List of Mission Planning Functions/Subfunctions

- Accept scheduling requests
 - Accept and validate observation requests
 - Generate engineering requests
 - Provide edit and override capability
- Generate mission schedule
 - Provide optimal observation ordering
 - Provide timeline editing tools
 - Validate schedule
- Perform guide star selection

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- Determine target visibility and availability
 - Check bright object constraints
 - Check object occultations
 - Determine spacecraft roll constraints
 - Check thermal constraints
 - Check radiation zone constraints
 - Check orbit day/night constraints
- Determine supporting resource requirements
 - Calculate data storage requirements
 - Determine power requirements
 - Calculate spacecraft maneuvers
 - Calculate solar array position
 - Determine LGA visibility
 - Determine OBC memory availability
 - Determine uplink and tracking contact needs
- Generate DOT
 - Translate observation schedule to DOT
 - Provide edit and override capability
- Provide support for OBC updates
- Generate reports and engineering displays
 - Display spacecraft activity timeline
 - Provide processing and error log displays and reports

AXAF FUNCTIONAL FLOW CONSIDERATIONS

Modularity/Standalone Capability

Because of its similarity to the HEAO-2 and Hubble missions and the unique mission planning features developed for them, the AXAF mission planning requirements were written with a strong emphasis on functional modularity and standalone operation. It is therefore not surprising that the resulting design approach also gives great importance to these considerations. Standalone operation and modularity greatly facilitate the reconfiguration of software data flows in response to flight contingencies, and minimizes maintenance costs.

Flow Sequence

The independence of mission planning and scheduling functional elements and the flexibility required of the scheduler module dictate the fundamental flow sequence of the AXAF Mission Planning and Scheduling concept. This fundamental principle is that all constraint calculations related to spacecraft ephemerides are completed before the scheduling process begins. The separation of orbital mechanics and scheduling functions in this manner allows independent development of each discipline and prevents coding entanglement that makes software maintenance difficult. The body of support data generated also facilitates troubleshooting analyses in contingency situations and reordering of functions as mission conditions change.

Another fundamental principle of the AXAF design concept is the clean division of the schedule generation function from the spacecraft management function. The former is concerned with determining what the schedule of activities will be, while the latter comprises all the spacecraft support (such as appendage movement) required to implement the schedule. Breaking the mission planning process at this point allows review of the spacecraft schedule by science and flight operations personnel before proceeding with the generation of detailed spacecraft functions and commands. Since communications networks require support requests 3-4 weeks prior to execution, mission schedules must be completed long before command generation is necessary. Thus the production of mission schedules as separate entities from the Detailed Operations Timeline simplifies schedule review and editing and reduces control center workload.

CONCEPT REFINEMENT

Based on the AXAF prototype concept, the generic mission planning and scheduling concept needs little refinement. As mentioned earlier, the only element in the original concept that needed more definition was Flight Operations Team Support. This problem appears to be satisfactorily resolved in the AXAF solution. By putting together subelements of the orbital mechanics function that are independent of schedule with environmental and spacecraft geometric displays, a much more definitive element is formed. In the authors' opinion this refinement improves the focus of this function.

In terms of process flow, further concept refinements can be realized by associating the communications planning function with the scheduling element instead of spacecraft management. This accounts for the scheduling of contacts based on engineering request selection criteria and facilitates schedule editing.

CONCLUSIONS

After comparing the AXAF mission planning and scheduling design concept with the generic concept, it appears that the generic model is valid, and that it can reasonably be expected that most future designs will comprise generic elements. The AXAF experience also suggests that orbit type is not as strong a design driver as previously thought. Before cancellation of the AXAF-S project, sufficient concept evaluation had been done to assure that a single mission planning and scheduling system could support both the highly elliptical, high orbit AXAF-I and the low polar orbit AXAF-S.

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As a result of the AXAF design work, the authors believe even more strongly that a generic system for space astronomy missions is well within reach for unmanned missions, and much of this system can be used for manned missions as well. The mission planning elements that have the best chance of forming a "core" system for all missions include (1) orbital mechanics, (2) observation and engineering request processing, (3) communications planning and (4) flight operations support. Once this core system has been standardized, the other functions can be incorporated one subfunction at a time. Eventually, this emphasis on generic systems will pay many dividends in the future by reducing software development and maintenance costs, simplifying user training and possibly even influencing spacecraft design.

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